Collaborative Proposal to Extend ONR YIP research with BRC Efforts

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LONG-TERM GOALS

The long-term scientific goals of this research project are:

1. To develop an understanding of how some sources of error affect ocean predictability.

2. To gain experience and develop ideas for the limitations to the predictability of oceanic processes.

OBJECTIVES

The primary objectives of this project are: (i) to undertand the importance of model uncertainty; (ii) to assess the influence of uncertainty on predictability; and (iii) to collaborate and learn from fellow BRC projects.

APPROACH

To improve forecasts of the ocean circulation, we must understand how various parameters can affect model uncertainty. The initial state of a model contains suboptimal parameterizations that may generate a significantly different flow. To understand the predictability of a flow, we must quantify how choices in the model parameters affect its temporal evolution. In this research, I intend to collaborate with Dr. Ralph Milliff on Bayesian techniques developed during the BRC efforts.

The ocean model used in this research is the ONR-funded Regional Ocean Modeling System (ROMS): a free-surface, hydrostatic, primitive equation ocean model discretized with a terrain following vertical coordinate system. The model has multiple sub-gridscale parameterizations of vertical mixing along with many options for open boundary conditions. Time-splitting of barotropic and baroclinic motions enables efficient time integration. ROMS has been successfully used to model many regions of the world ocean (see http://www.myroms.org/papers) and is a widely used community resource.

ROMS currently contains over 70 adjustable parameters that affect the physics of the time integration. The initial efforts are focussed upon the parameters that directly affect the assimilation of data. Both variational and ensemble assimilation methods require knowledge of the

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background error covariance matrix, **P**. Unfortunately, we do not know the natural covariance of the ocean, and we must make estimates of the matrix. To accomplish this, **P** is constructed from the univariant components and — assuming Gaussianity — a diffusion operator to estimate the spatially covarying fields. The diffusion operator relies upon estimates of length-scales for a given application, and the performance of the assimilation is sensitive to these estimates. In the early phase of this effort, we have worked to understand the length-scale assumptions employed in data assimilation and optimal interpolation schemes.

In future work, we aim to employ Bayesian techniques to develop statistical models of model uncertainty, and this work will begin later in year 2 of this program.

WORK COMPLETED

During the current reporting period, we have worked to understand the statistical variability of the ocean around the Hawaiian islands. To this effect, we have collaborated with Ralph Milliff to employ the technique of semi-variograms to analyze a decade of observations from the region in order to determine the optimal dynamical length-scales in the region around the main Hawaiian islands. This has culminated in a paper submitted for publication: Matthews et al. (2010).

During the summer of 2010, collaborators Andrew Moore at UCSC and Hernan Arango at Rutgers held a 5-day workshop on ROMS assimilation for the benefit of the ROMS community at the University of California. As one of the primary users of the assimilation framework, I and one of my postdocs attended this meeting to help conduct tutorials and talks to assist with the training of new users.

RESULTS

The dynamics of the ocean vary on a wide range of spatial and temporal scales from millimeters to hundreds of kilometers and seconds to decades. Of course, for most regional applications, these range of scales are not applicable, and determining the dominant dynamical scales for the region of interest is a difficult challenge. Most optimal interpolation and assimilation procedures are sensitive to these dynamical scales and an accurate estimation is required. As part of the ongoing efforts of my Young Investigator Program award as well as the operational NOAA Integrated Ocean Observing System, we have built an operational, real-time assimilation and prediction system for the main Hawaiian islands. This system provides a foundation laboratory for research into state estimation and predictability. In support of these efforts, we have worked to understand how to best determine the dominant dynamical length-scales of the region.

Using four years of satellite sea surface height, satellite sea surface temperature, and *in situ* data from the Hawaiian Ocean Time-series (HOT), Argo, and local autonomous glider missions, we have found the spatially varying, dynamical length-scales around the islands. The satellite data provide the horizontal scales and the *in situ* data the vertical (to 2,000 m). Using these sparse data, we employed the semi-variogram method to determine the spatial covariance of available observations. First, the semi-variogram is computed for each set of data and an exponential function is then fit to the data. This exponential fit provides a numerical model for the variance as a function of distance (or lag). This function is then evaluated to determine the range (the dominant dynamical length-scale) and variance.

The Hawaiian island chain rises from the sea floor to well over 4km above MSL, creating a disturbance in both the oceanic and atmospheric flows. This interference should create differing

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dynamical scales on the windward and leeward sides of the islands. As shown in both figures 1 and 2, we find that this is the case. The range estimates on the windward side of the island are significantly longer than in the leeward, where a strong eddy field exists due to the impinging islands. Interestingly, these differences were not apparent in the vertical length-scale estimates. The vertical range estimates — as expected — are found to be sensitive to the mixed layer as shown in figure 3.

These results guided our setup of the Hawaiian islands assimilation system. Currently, the ROMS assimilation system allows only a single horizontal length-scale per variable (zeta, temperature, etc.) to be specified for the entire region. As this work has shown, this is inadequate for the Hawaiian application; however, some preliminary tests have found that the median length-scales derived from this work are effective and the assimilation is proceeding successfully.

Not shown, we have built a North Atlantic experiment, and the assimilation was found to be very sensitive to the length-scales as determined by the semi-variogram technique, which provide us with confidence as we proceed forward.

IMPACT/APPLICATIONS

Understanding the dynamical length-scales is of significant importance for applications such as optimal interpolation and data assimilation. This method of semi-variogram is robust and generalized, and is applicable to any oceanic or atmospheric region. We have found that proper length-scales are crucial to the performance of the assimilation procedure, and it is important for most such applications to accurately describe the dominant dynamical scales.

TRANSITIONS

These methods were presented at the ROMS Data Assimilation Workshop held at UCSC in the summer of 2010, and have been submitted to the Journal of Geophysical Research. We hope that more people in the community will employ them in their own applications.

RELATED PROJECTS

This project is collaborating with the following ONR supported projects:

- "A community Terrain-Following Ocean Model (ROMS)", PI Hernan Arango, grant number N00014-08-1-0542.

- "The ROMS IAS Data Assimilation and Prediction System: Quantifying Uncertainty", PI Andrew Moore, grant number N00014-08-1-0556.

REFERENCES/PUBLICATIONS

D. Matthews, B. S. Powell, and R. F. Milliff. Characteristic ocean length scales around the Hawaiian Islands. *J. Geophys. Res.*, submitted, 2010.
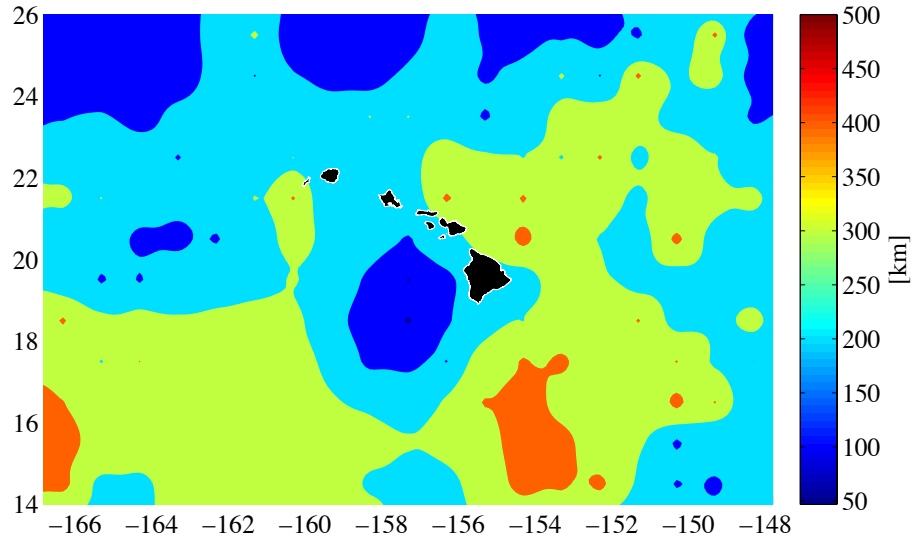
Figure 1: Range estimates generated from the semi-variogram of 4 years of AVHRR data.
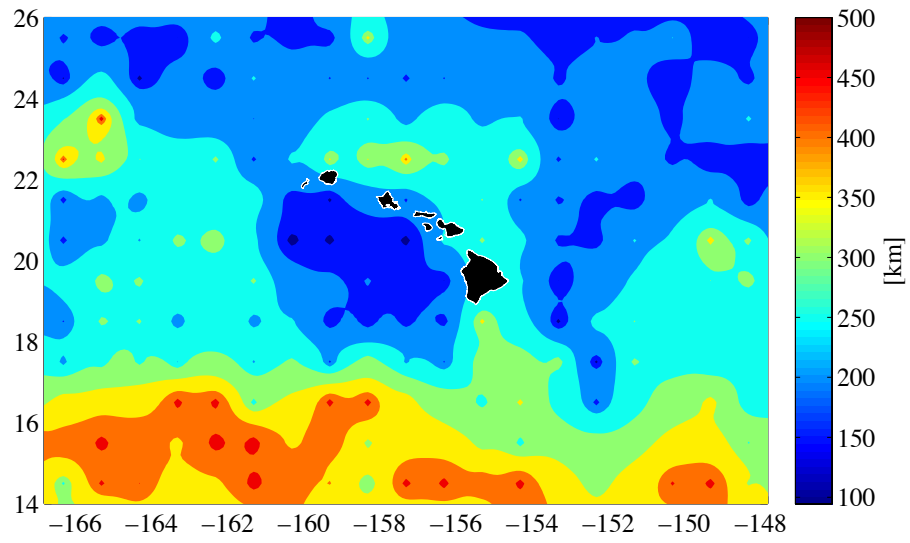

Figure 2: Range estimates generated from the semi-variogram of 4 years of Aviso data.
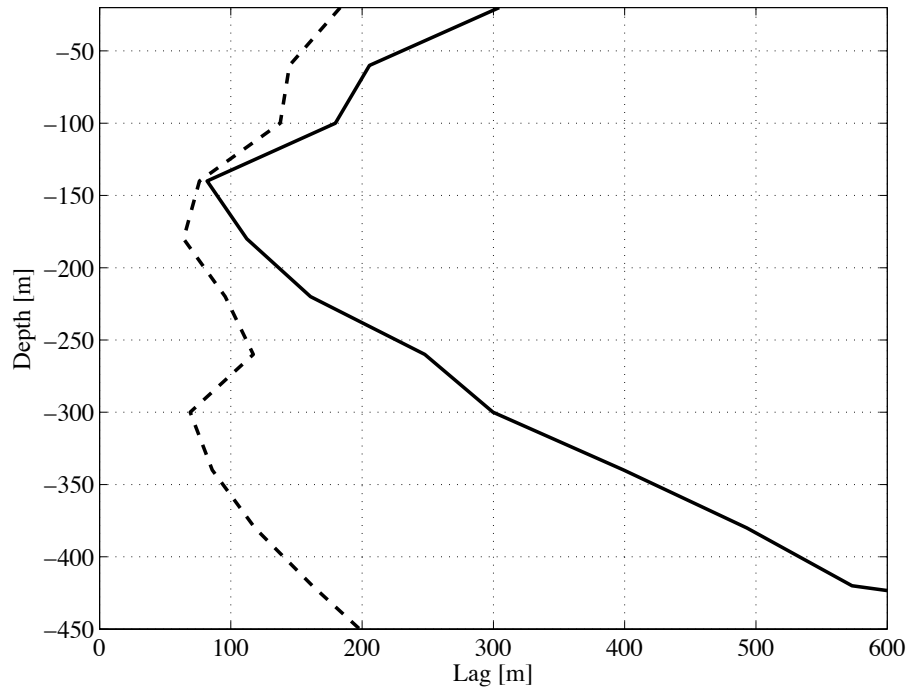
Figure 3: Vertical range estimates generated from the semi-variogram of 4 years of *in situ* data for temperature (solid line) and salinity (dashed line).